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The fate of pesticides in soil and aquifers taking a small-scale view: Does spatial heterogeneity in degradation potentials have an impact?

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Pesticides are chemicals intentionally introduced to the environment, and they are highly regulated because of their environmental impact. Large amounts of pesticides are used in agricultural production and pollution of groundwater aquifers is often seen. There is, however, a striking difference between the input levels (up to several kg per hectare) and the concentrations detected in groundwater, which are normally in the microgram to nanogram per litre range.

Soils and sediments are very complex and heterogeneous environments, where microorganisms and nutrients are unevenly distributed. As a consequence, microbial mineralisation of pesticides may also be unevenly distributed (Sebai, *et al.*, 2007, Batioğlu-Pazarbaşı, *et al.*, 2012, Badawi, *et al.*, 2013a). Little is known, however, about how these variations/heterogeneities affect overall degradation and leaching of pesticides to groundwater aquifers.

Using a 96-well microplate mineralisation assay we analysed how the mineralisation potential of phenoxy acid herbicides (MCPA, and 2,4-D) spatially varied in soil, subsoil and groundwater aquifers at the cm scale. In the top soil, all samples showed rapid mineralisation following Monod mineralisation kinetics (figure 1). In the subsoil, a more heterogeneous distribution of mineralisation potential was observed, with fewer samples showing rapid mineralisation and more samples showing either slow 0-order mineralisation kinetics or no degradation. The impact of this microbial heterogeneity on degradation and leaching of MCPA through the upper one meter sediment was evaluated using a reactive transport model of the upper 1m of unsaturated soils set up in COMSOL Multiphysics. Monod kinetics was fitted to the individual curves to derive initial degrader biomass values, which were incorporated in the model to simulate heterogeneous biodegradation. Six scenarios were set up to evaluate the effect of different degrader biomass distributions (homogeneous, heterogeneous, or no biomass), and either matrix flow or preferential flow through a soil matrix with a wormhole. MCPA leached below 1 metre within 250 days, only when degrader biomass was absent and preferential flow occurred. Biodegradation in the plough layer contributed significantly to reduce MCPA leaching. If high microbial degradation rates are concentrated around fast flow paths such as wormholes then MCPA-leaching below one metre was significantly reduced.

To verify whether biopores are hot spots for microbially-mediated pesticide mineralisation we identified hydraulically active biopores in a test plot of an agricultural field by percolating brilliant blue through the soil. Small portions of soil (500 mg) were sampled at approx. 1-cm distances along a transect covering 10 biopores and adjacent matrix soil at two depths: 30 cm below ground surface (b.g.s.; transition zone below the plough layer), and 55 cm b.g.s. (subsoil). Specific pesticide degrader populations were enumerated by the most probable number (MPN) method, and pesticide mineralisation was quantified by a ¹⁴C-mineralisation assay (Johnsen *et al.*, 2009). Compared to the matrix soil, increased density of MCPA degraders and MCPA miner-

alisation was observed in the transition zone, but not in the subsurface (Badawi et al., 2013b). We therefore conclude that hydraulically active biopores may be hot spots for pesticide mineralisation, but that this biopore effect may be limited in subsoil with low densities of degrader populations and MCPA mineralisation potentials.

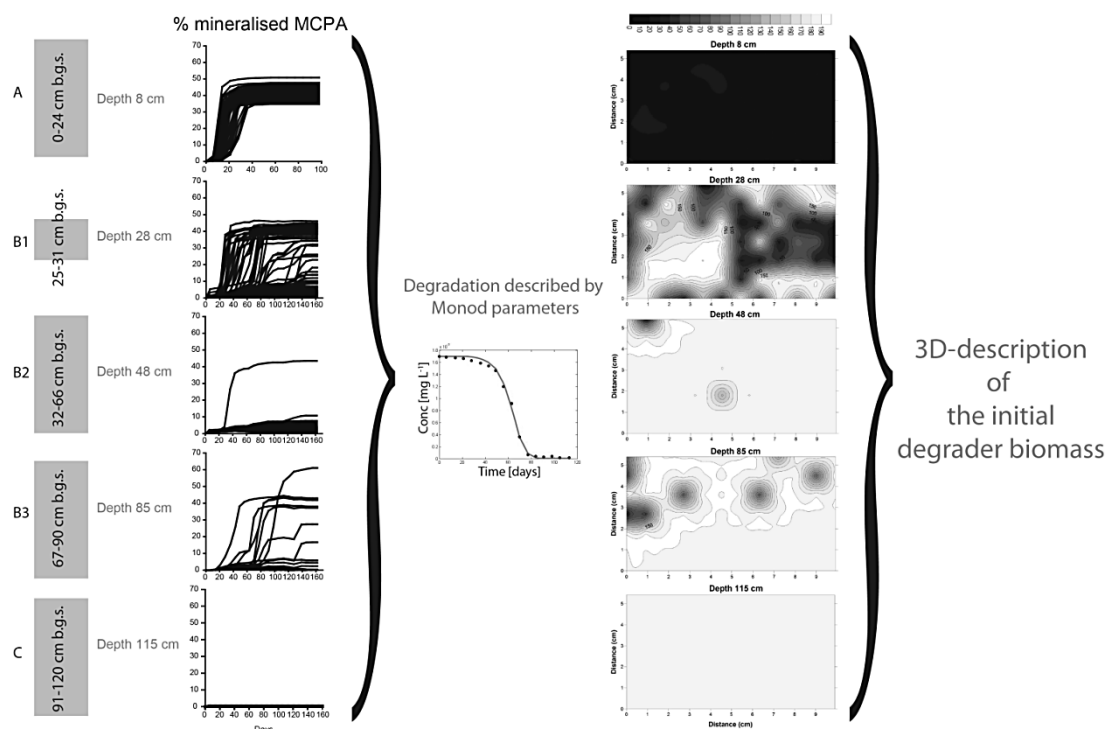


Figure 1: Centimetre scale spatial distributions of MCPA mineralisation potentials in soil from the plough layer (A), the B horizons (B1, B2 and B3) and the C horizon (C). Monod kinetics was fitted to the individual curves to derive initial degrader biomass values, which were incorporated in a reactive transport model to simulate heterogeneous biodegradation. The spatial distribution of mineralisation potentials were further visualized using 2D mapping.

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